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CHARACTERIZATION OF SQUIB MK 1 MOD 0; SENSITIVITY TO 9KMC RADAR PULSES

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UNITED STATES NAVAL ORDNANCE LABORATORY, WHITE OAK, MARYLAND

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CHARACTERIZATION OF SQUIB MK 1 Mod 0; SENSITIVITY TO 9KMC RADAR PULSES

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ABSTRACT: Mk 1 Mod 0 Squibs were fired in the wave guide of a 9KMC radar. For fully loaded squibs, on the basis of previous tests at D.C. to 5 megacycles, the bridgewire in the 9KMC tests did not reach the temperature expected necessary for firing. Squibs without cup or base charge approximated the expected firing temperature. From the results it is inferred that squib simulators used to predict firing on the basis of bridgewire temperature may not be applicable at frequencies as high as 9KMC. It is also hypothesized that the powder charges in some devices may act as attenuators somewhat reducing the probability of firing in high frequency RF fields.

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Characterization of Squib Mk 1 Mod 0; Sensitivity to 9KMC Radar Pulses

This report describes work to determine the response of the Mk 1 Mod 0 Squib to 9 KMC radar pulses. The work was sponsored by the HERO program, Task NOL 443.

It is believed that the results are significant in that they point out the possible inapplicability of using the bridgewire temperatures of EEDs to predict their response to frequencies as high as 9KMC.

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By direction

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INTRODUCTION

1. This report describes some preliminary experiments to determine the response of the Squib, Mk 1 Mod 0, to 9KMC radar pulses. The firing of electro-explosive devices (EEDs) by RF energy has been the subject of rather intensive investigation under the Bureau of Naval Weapon's HERO (Hazard of Electromagnetic Radiation to Ordnance) program of which this study was a part. The HERO program was initiated by the proven unintentional firing of EEDs by RF energy; the suspicion that the frequency of such accidental firings might, if the problem were neglected, increase with the increasing power of military RF transmitters; and the desire to prevent by reasonable means the consequences of the inadvertent firings.

2. The Naval Ordnance Laboratory was given the task to determine the response of EEDs to electrical energy. It was hoped that a generalized concept of how an EED reacts to electrical pulses could be developed and extended to predict expected responses of EEDs when contained in ordnance subjected to RF environments. The Squib, Mk 1 Mod 0 (Figure 1) was originally chosen for the NOL studies. The Squib, Mk 1 Mod 0, is a typical wire bridge EED. It was available in quantity from production and was of special interest because it was involved in the early accidental firings by RF of 2.75 inch rockets. A considerable amount of experimental work has now been done at NOL with this squib. This work has resulted in a mathematical model for the squib's response to electrical stimuli (1); the development of instrumentation necessary to measure the physical constants associated with the squib and involved in the mathematical model (2), (3), (4), (5); the measured response to capacitor discharge and to energy supplied at 5 megacycles RF (6), (7), (8), (9), (10); and comparisons of predicted and measured responses when the mathematical model is combined with the "hot-spot" theory of explosive initiation (11), (12), (13), (14). All of the experimental work extending from DC firing to firing at a frequency of 5 megacycles indicated that the mathematical model developed was adequate to describe the response of the squib over this range.

3. In the model developed the energy delivered to the squib was assumed to be dissipated as heat in the bridgewire. If the temperature elevation of a small volume of explosive in contact with the bridgewire was large enough, initiation occurred. For frequencies up to 5 megacycles (and probably

somewhat higher) the assumption that all the power was dissipated in the bridgewire appeared reasonable. For squibs such as the Mk 1 Mod 0 in a radar field of frequency = 9KMC ($\lambda \cong$ 3cm) it could be expected that energy might be absorbed in physical parts other than the bridgewire. In addition, at frequencies as high as 9KMC it was possible that large potential differences could exist between different parts of the squib structure and might result in internal arcing possibly through the explosives. The dissipation of energy other than in the bridgewire by either of these mechanisms, if large enough, could possibly lead to firing. If appreciable energy were dissipated other than in the bridgewire the mathematical model developed would not apply. The tests of this report were to a large extent made to determine whether or not the mathematical model did apply at the 9KMC frequency.

THE MODEL AND ITS APPLICATION TO RADAR PULSES

4. The mathematical model postulated was:

$$C_p \frac{d\theta}{dt} + \gamma \theta = P(t),$$

where:

C_p = heat capacity of bridge system

θ = temperature rise above ambient

t = time

γ = heat loss factor

$P(t)$ = time dependent power input

If the physical constants C_p and γ are known, solutions to the equation can be found for different $P(t)$ inputs which give θ as a function of t. If the hot spot theory of explosive initiation (15) is assumed, explosion will occur when θ reaches about 500°C above ambient. As previously noted, instruments were built with which C_p and γ were measured. These values for the Mk 1 Mod 0 Squib are $C_p = 2.4 \times 10^{-6}$ watt-sec/°C, $\gamma = 6.0 \times 10^{-4}$ watts/°C. The equation has been applied for radar type inputs to the Squib, Mk 1 Mod 0 (11), (12), (13), (14), (16). It was assumed that the input takes the form of a constant current square pulse alternating with an off time. The assumed constant current pulse is a conservative one for safety estimates as it introduces regenerative heating due to the positive temperature coefficient of resistance of the

bridgewire. The equation for a constant current input is:

$$C_p \frac{d\theta}{dt} + \gamma \theta = I^2 R_o \quad (1 + \alpha \theta)$$

α = the coefficient of resistance corresponding to R_o

R_o = resistance at beginning of each current pulse.

The solution is:

$$\theta = \frac{I^2 R_o}{\gamma - I^2 R_o \alpha} \left[1 - \exp \left(\frac{I^2 R_o \alpha - \gamma}{C_p} \right) t \right] .$$

When the pulse is shut off

$$C_p \frac{d\theta}{dt} + \gamma \theta = 0$$

and

$$\theta = \theta_o \exp -\left(\frac{\gamma}{C_p} \right) t,$$

where:

θ_o = temperature at end of constant current pulse

t = 0 at beginning of the off period.

5. The results of applying these equations to the Squib, Mk 1 Mod 0, for several different current amplitudes at an "on-time" of 2 microseconds followed by an "off-time" of 2 milliseconds are shown in Figures 2 and 3. The "thermal stacking" which occurs mathematically had been qualitatively predicted much earlier (17). Figure 4 shows actual oscillograms of the resistance (and consequently, the temperature with a suitable proportionability factor) of the bridgewire of the Mk 1 Squib in a 9KMC radar wave guide. It shows the stacking to be of the form predicted.

THE EXPERIMENTAL APPARATUS

6. For the experimental firing program the Squib, Mk 1 Mod 0, was mounted in the radar wave guide of the arrangement shown in Figure 5. The 50-watt average power output from the modulator worked into a dummy load. A 15-db cross-coupler syphoned off a portion of the modulator output. The squib was mounted in one arm of the cross-coupler and a slideable short in the other. Beyond the squib a copper plate with a small hole in it was placed across the wave guide. This plate was needed to re-

flect energy by-passing the squib back into the wave guide. Without it, it was difficult to fire the squibs. The arm of the cross-coupler containing the squib was slotted in the E plane and stuffed with styrofoam. This was done to prevent the gases and particles from the exploding squib to damage or foul the apparatus. The squibs were mounted in a holder as shown in Figure 6. The holder was clamped to the wave guide with the squib lead wires clamped between the wave guide and the holder in fixed orientation in the H plane.

7. Two types of firings were conducted during the program:

a. continuous operation

b. gated pulse operation.

8. For continuous operation the apparatus was as above. The squib was mounted to the wave guide, the radar was turned on, and the slideable short moved until the position which gave maximum power absorption at the squib was reached. This usually took in excess of 15 seconds. Notation was made as to whether the squib fired. The method used to determine the position of maximum energy absorption (maximum temperature of the bridgewire) will be described in a later section of this report.

9. For gated pulse operation the apparatus described was modified so that a controlled number of pulses could be delivered to the squib. The modification consisted of using a preset counter pulser to ground the input grid of the cathode follower in the thyratron triggering circuit of the modulator. The grounding took place through a capacitor. It was found that to obtain the desired number of pulses into the squib the counter pulser had to be set for 5 less than the desired number of radar pulses. In conducting a test the squib was mounted to the wave guide, the slideable short was positioned to a point where maximum heating was expected*, the counter pulser was set for the desired number of input pulses, and the radar turned on to pulse the squib. Notation was made of whether or not the squib fired and of the maximum bridge temperature monitored. The method of monitoring will be discussed below.

*The short was set to a fixed position on the basis of experience with continuous pulse operation.

MONITORING THE BRIDGEWIRE TEMPERATURE

10. To measure the temperature of the bridgewire, the bridgewire itself was used as its own resistance therometer. A small constant current of 50ma was passed continuously through the bridgewire when a squib was being tested. The voltage across the bridgewire was measured concurrently. Consequently the resistance using Ohms Law is known as a function of time. The coefficient of resistance (α) of the bridgewire was then used as the proportionality factor to relate resistance and bridgewire temperature thus:

$$\theta = \frac{1}{\alpha} \left(\frac{R_t - R_o}{R_o} \right)$$

where:

R_t = resistance of bridgewire at any time

R_o = initial cold resistance of bridgewire

This method is extremely simple and sufficiently accurate to obtain meaningful measurements. The constant current (50ma) is chosen sufficiently low so that the elevation in the bridgewire temperature which it alone produces is low compared to the temperature needed for firing.

11. No attempt was made to measure either the power or the energy delivered to the squibs as a whole. There is no doubt that during these radar experiments energy is being absorbed by the squib other than in the bridgewire. The absorption of energy other than in the bridgewire could be of significance. However, our purpose here was to test whether or not the squibs conformed to the mathematical model at the 9KMC frequency as it had at all tested frequencies up to 5 megacycles. For this purpose the bridge temperature is the significant measurement needed.

12. Several methods were used to measure the voltage drop across the bridgewire. For the case where the radar was turned on and allowed to run continuously the voltage measurement was first made using a Sanborn Recorder (Twin viso model 60-1300).* However, this instrument did not have sufficient sensitivity and the total deflection was too small to obtain readings of the desired significance. Some few attempts were made to use a 60 cycle RMS a.c. voltmeter, but one could not accurately make a reading just before the needle went off scale when the squib fired. An oscilloscope was selected as the means of making the voltage measurement. The scope was allowed to retrace and

*Similar instruments manufactured by other Companies could have been used with equal facility.

the highest reading obtained before the very rapid rise in voltage (shown in Figure 7 by the large number of individual lines above the almost opaque mass of retraces) resulting from the heat feed back from the burning explosive was selected as the voltage to be used in making the temperature calculation. During the test the slideable short was adjusted to obtain squib firing. In several cases however, the squib could not be fired. Here the highest voltage on the trace was used to calculate the final temperature attained by the bridgewire. Typical oscillograms are shown in Figure 7.

13. For the gated pulse operation the total duration of the input signal was precisely known in advance. Retracing was not necessary, and it was consequently possible to obtain an accurate oscilloscopic reading of the voltage across the bridgewire as a function of time. From the traces so obtained the points corresponding to firing of the squibs could be selected. These points occurred when the heat produced by the explosion caused a rapid rise of the voltage across the bridgewire. A typical oscillogram is shown in Figure 8.

RESULTS

14. The results for the continuous mode of firing are given in Tables I and II. Table I was obtained using the Sanborn Recorder and Table II the oscilloscope as discussed above. As can be seen the temperatures observed at the bridgewire are considerably lower than the expected 400-500°C firing temperature. It was thought at first that the low results might possibly be due to the inaccuracy of the measurement. However, after the gated pulse tests were run with certain innovations it was apparent that although the observed low temperatures might be somewhat imprecise they were nevertheless an accurate indication of an existing low temperature condition at the bridgewire when the squibs fired.

15. The results for the gated pulse firing are given in Tables III, IV, and V. Table III data were obtained on fully loaded devices at 40 pulses; Table IV information was obtained on fully loaded devices subjected to 100 pulses. An inspection of these tables shows that a number of firings occur at extremely low bridgewire temperatures (i.e. about 150°C). Moreover, it was noted that a large number of squibs did not fire at all. Ordinarily this might have been interpreted as due to poor positioning of the squib in the wave guide (a fairly critical factor for good power absorption). However, during preliminary adjustments of the radar system a number of trial and error firings were carried out using the plug and bridgewire with the spot charge only, i.e. the cup and base charge were removed. It was noted at that time that firings occurred in virtually every case.

16. It was therefore decided to run a test, the data for which are given in Table V. In this test squibs were divided into two groups. One portion of the squibs was left intact. The other portion was modified by removing the cup and base charge. A test series was then run wherein some of the modified squibs were tested in the radar firing apparatus; some of the fully loaded squibs were then tested under the same conditions, and finally the remainder of the modified squibs was tested. The sequential type firing was performed to eliminate any effect of radar drift during the test series. An inspection of the results in Table V confirms the previous observation. With wire and spot charge only, firing occurs in almost every case and the temperature of the bridgewire while lower than anticipated is not excessively low. With the cup and base charge present a large number of misfires occurs, power absorption at the bridgewire is much poorer, and most important the temperatures observed at the bridgewire at the time of firing is quite low in many cases.

DISCUSSION OF RESULTS

17. The results of fully loaded Mk 1 Squibs fired in the wave guide of the 9KMC radar indicate that the mathematical model previously found to hold from D.C. through 5 megacycle R.F. was not applicable. Temperatures observed at the bridgewire were much lower than the 400 to 500°C expected. For squibs modified by removal of the cup and base charge, results approaching those predicted by the previously proposed model were obtained. However, even here the temperatures in some few cases were about 100°C lower than expected. It was also observed that with the cup and base charge removed all of the squibs tested fired. When full loaded squibs were tested the incidence of firing was lower. For gated pulse operation where the squib was fixed in a single position the incidence of firing was lowest. In the case of continuous operation where tuning was performed during the test not all squibs fired.

18. From these results and the fact that VSWR* tests show that considerable power is absorbed other than in the bridgewire it is apparent that firing in many cases during the testing described was not due to the heating of the bridgewire, but rather to energy delivered by another heating mechanism. The fact that firings at low bridgewire temperatures occurred with as few as 40 pulses indicates further that it is not a bulk heating of the explosive which is taking place. At the 9KMC frequency voltages exist between various portions of the squib structure. These voltages lead to current flow and in some cases it is hypothesized that this current channels between the lead wires and the cup through the sensitive primary explosive and

* Some few tests were performed but not reported here.

causes the squibs to fire. Removal of the cup leaving the bridge and spot charge in air makes such alternate paths unlikely, and the firing once again reverts to nearly that caused by elevated bridgewire temperatures. It is possible also that the black powder being conductive absorbs energy by current flow through it and between various portions of the cup. This could account for the reduced frequency of firing.

19. From the HERO standpoint these results could be highly significant because they point up the fact that simulators used to detect the degree of heating at the bridgewires of EEDs might give erroneous indications of whether or not a device would have fired. Further, the results indicate that the powders of certain EEDs might themselves be attenuators of incoming RF energy and absorb appreciable amounts of the total energy being delivered to the squib. Clever designs could possibly take advantage of such a phenomenon to reduce the probability of firing from short duration exposures to RF fields.

20. Finally, it should be pointed out that the data gathered in the gated pulse firing portion of the tests is possible of more extensive evaluation. It would, for instance, with further analysis, be possible to determine the elapsed time to firing, the pulse or which firing occurred and also to calculate the delivered energy up to the firing point. In the interest of reporting the more pertinent results within reasonable time and in the belief that the important conclusions would not be altered, the more elaborate determinations were not made up to the writing of this report.

TABLE I

Continuous Pulse Firing Using The Sanborn Recorder (Fully Loaded)

R_O (ohms)	Total Deflection (mv)	R_F (ohms)	θ_F (°C)	Result
0.98	56.4	1.13	219	X
1.09	63.0	1.26	223	X
0.95	52.4	1.05	150	O
0.99	57.0	1.14	216	X
0.96	54.6	1.09	193	X
1.02	57.4	1.15	182	X
1.00	56.0	1.12	171	X
1.02	61.0	1.22	280	X
1.08	60.5	1.21	172	X

X = Fire

O = Misfire

TABLE II

Continuous Pulse Firing Using The Oscilloscope (Fully Loaded)

R_o(ohm)	Total Deflection(mv)	R_F(ohms)	θ_F(^oC)	Result
1.03	60.5	1.21	250	X
1.20	70.5	1.41	250	X
1.03	60.5	1.21	250	X
0.99	58.5	1.17	260	X
0.97	59.0	1.18	309	X
1.09	64.0	1.28	249	X
1.01	59.5	1.19	255	X
1.13	69.5	1.39	329	X
1.01	58.5	1.17	226	X
1.04	64.0	1.28	330	X
1.05	58.5	1.17	163	O
1.10	63.5	1.27	221	O
1.03	63.5	1.27	333	X
1.07	66.0	1.32	334	X
1.10	63.0	1.26	208	O
1.01	57.5	1.15	198	X
1.16	70.5	1.41	308	X
0.91	53.5	1.07	251	O
1.05	65.0	1.30	340	X

TABLE III

Gated Pulse Firing - 40 Pulses
(Fully Loaded)

R_o(ohm)	Total Deflection (mv)	R_F(ohms)	θ_F(^oC)	Result
1.02	62.0	1.24	280	X
1.02	55.0	1.10	112	O
1.01	56.5	1.13	170	O
0.99	56.0	1.12	188	O
1.10	67.0	1.34	312	X
1.00	59.0	1.18	257	X
0.96	53.0	1.06	149	X
0.96	53.0	1.06	149	O
1.02	63.0	1.26	336	X
1.06	58.0	1.16	135	O
1.05	57.5	1.15	136	O
1.06	58.5	1.17	148	X
1.14	68.0	1.36	276	X
0.99	55.0	1.10	159	X
1.00	61.0	1.22	314	X
0.94	49.5	0.99	76	O
1.02	58.0	1.16	196	O
0.99	59.0	1.18	274	O
1.00	63.0	1.26	371	X

Continued on Next Page

TABLE III
(Continued)

R_o(ohm)	Total Deflection (mv)	R_F(ohms)	θ_F(^oC)	Result
1.00	55.5	1.11	157	0
1.06	64.0	1.28	296	X
0.91	56.5	1.13	345	X
1.09	57.0	1.14	66	0
1.21	66.5	1.33	142	0

TABLE IV

Gated Pulse Firing - 100 Pulses
(Fully Loaded)

R_o(ohm)	Total Deflection (mv)	R_F(ohm)	θ_F(°C)	Result
1.09	69.5	1.39	393	X
0.95	53.5	1.07	180	X
1.10	63.0	1.26	208	X
0.97	62.5	1.25	412	X
0.99	55.0	1.10	159	O
1.02	63.0	1.26	336	X
0.95	52.5	1.05	150	O
0.90	58.0	1.18	444	X
0.99	53.0	1.06	101	O
0.97	53.0	1.06	1.33	X
1.02	61.0	1.22	280	O
1.00	53.5	1.07	100	O
1.01	56.0	1.12	156	O
1.22	68.5	1.37	176	O
1.06	57.5	1.15	121	O
1.04	63.5	1.27	316	X
1.15	70.5	1.41	323	X
0.99	52.5	1.05	87	O
1.07	64.5	1.29	294	X

TABLE V

Gated Pulse Firing - 50 Pulses
(No Case Spot Charge)

R_o(ohm)	Total Deflection (mv)	R_F(ohm)	θ_F(^oC)	Result
1.00	62.5	1.25	357	X
0.99	60.5	1.21	317	X
1.04	64.5	1.29	343	X
1.02	64.5	1.29	378	X
0.97	61.5	1.23	383	X
0.97	62.0	1.24	398	X
0.98	63.0	1.26	408	X
		(Fully Loaded)		
1.00	59.0	1.18	257	X
0.93	50.5	1.01	123	0
1.03	57.5	1.15	166	0
1.05	64.5	1.29	327	0
0.90	51.5	1.03	206	X
1.02	60.5	1.21	266	X
1.00	57.0	1.14	200	X
0.89	48.5	0.97	128	0
1.10	63.0	1.26	208	0
0.97	53.0	1.06	133	0

(Continued on Next Page)

TABLE V (Cont'd)

(No Case, Spot Charge)

R_o(ohm)	Total Deflection (mv)	R_F(ohm)	θ_F(^oC)	Result
0.95	60.0	1.20	376	X
0.98	62.5	1.25	394	X
1.09	67.5	1.35	341	X
0.90	56.5	1.13	365	X
1.07	64.5	1.29	294	X
0.98	62.0	1.24	379	X
0.93	59.0	1.18	384	X
0.94	60.0	1.20	395	X
0.98	60.5	1.21	335	X

NOTES:

1. IGNITION BEAD - APPROX. 5 MG DDNP/$KClO_3$
2. FLASH CHARGE - APPROX. 45 MG BLACK POWDER
3. BASE CHARGE - APPROX. 45 MG BLACK POWDER
4. BRIDGE WIRE - .001" PLATINUM - IRIDIUM .060" LONG

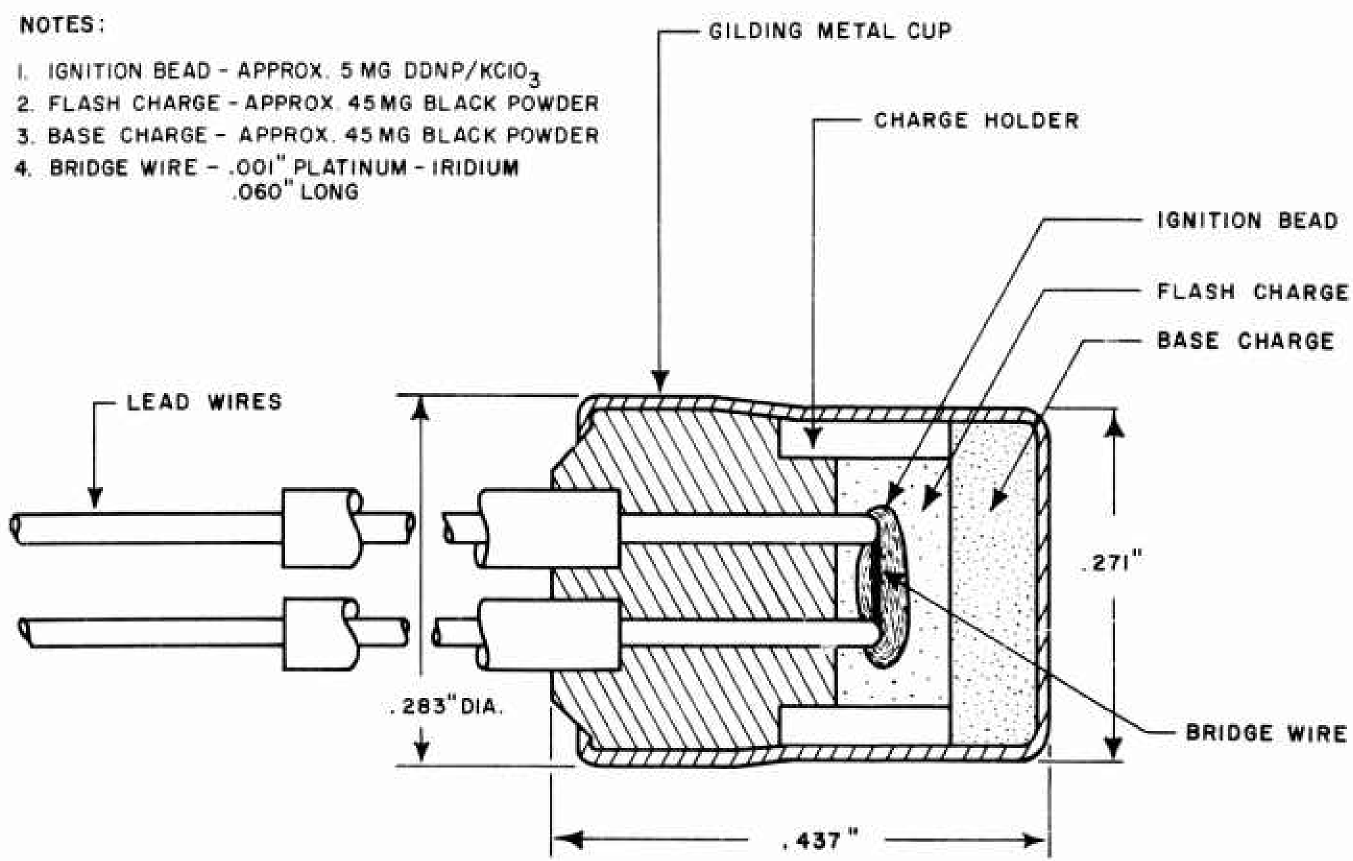


FIG. 1 SQUIB MK1 MOD 0

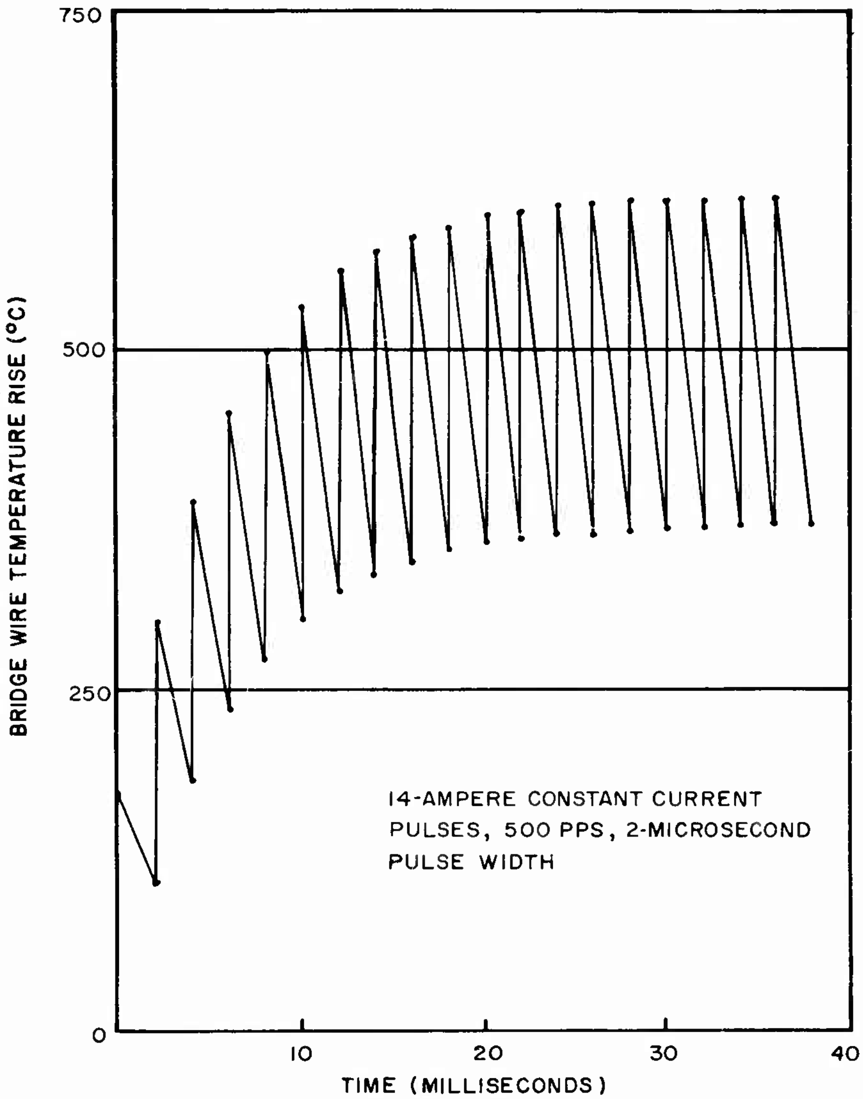


FIG. 2 THERMAL STACKING OF THE MK1 SQUIB BRIDGE

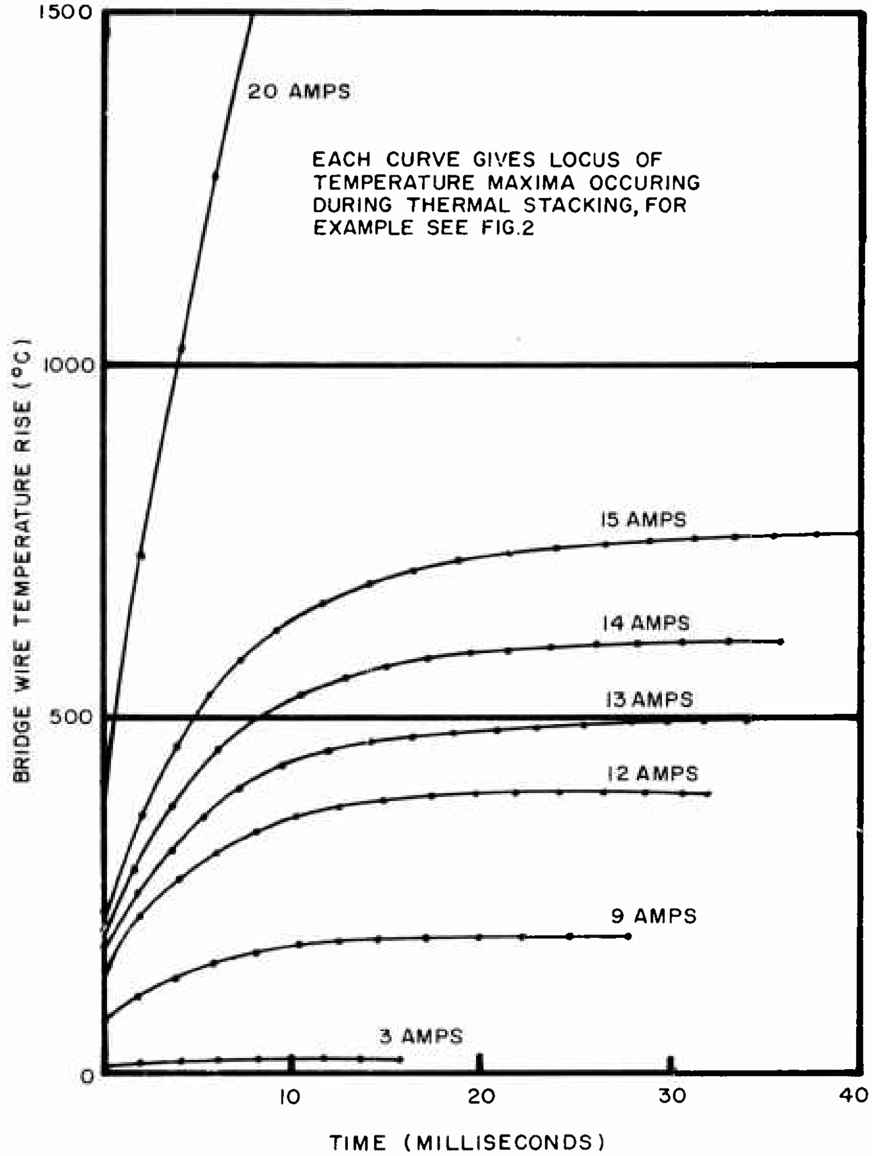


FIG. 3 THERMAL STACKING OF THE MKI SQUIB BRIDGE AS A FUNCTION OF PULSE AMPLITUDE (CONSTANT CURRENT PULSES, 500 PPS, PULSE WIDTH 2 MICROSECONDS).

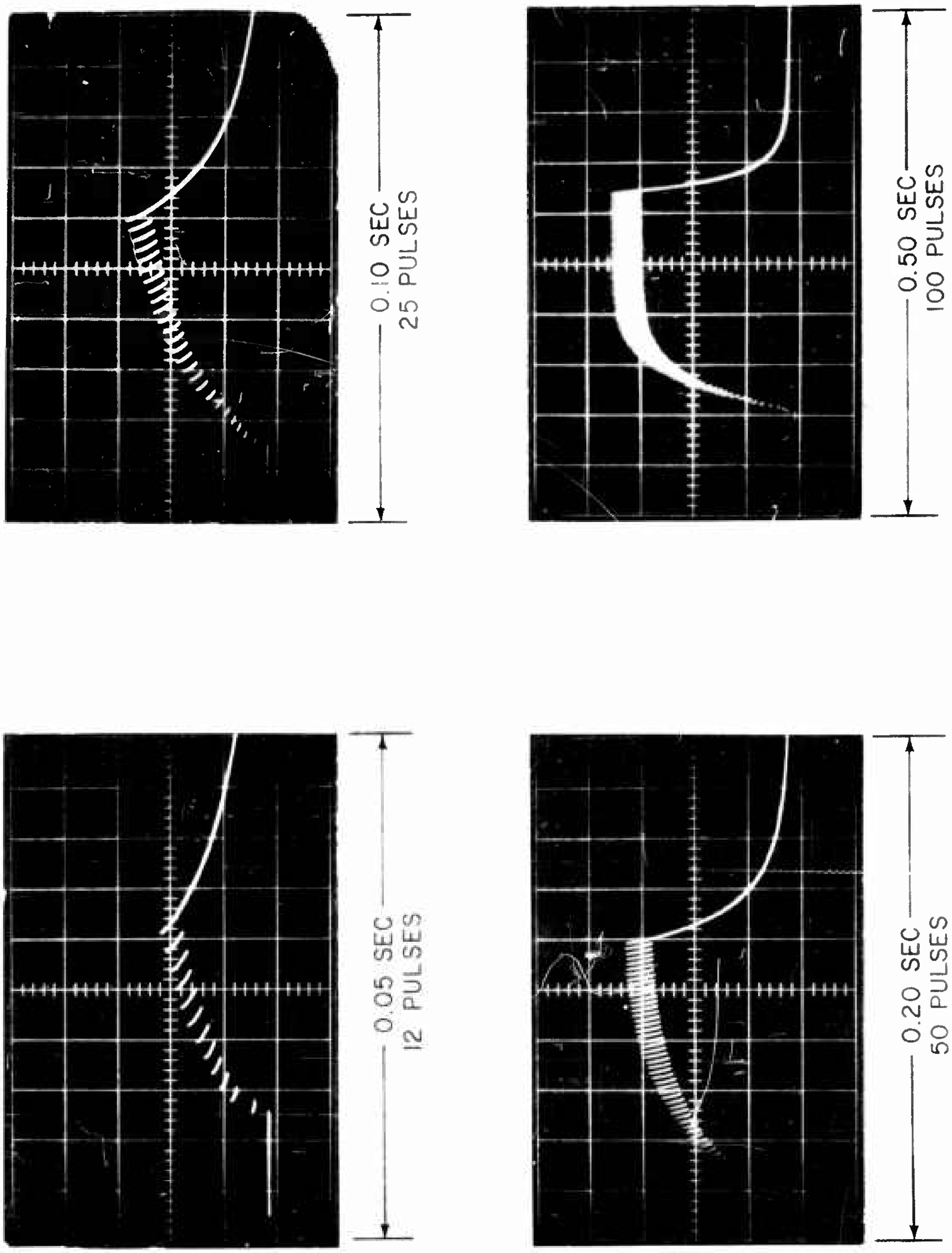


FIG. 4 OBSERVED THERMAL STACKING OF SQUIB BRIDGE-WIRE DURING 9KMc RADAR TEST

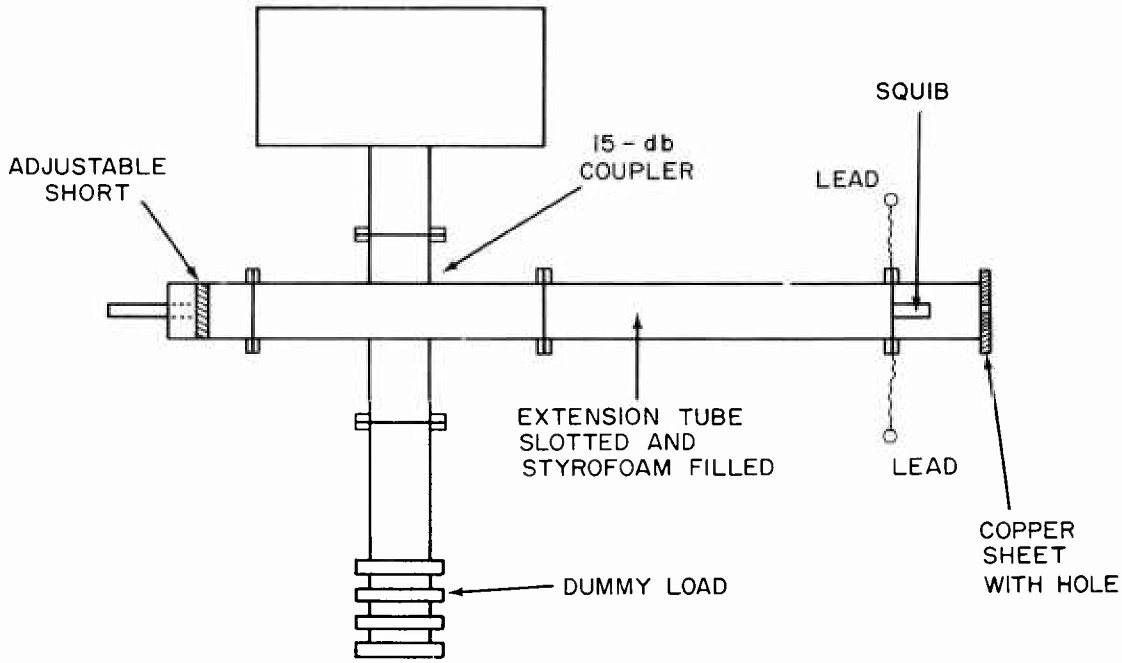


FIG. 5 APPARATUS FOR 9-KMC FIRING TESTS

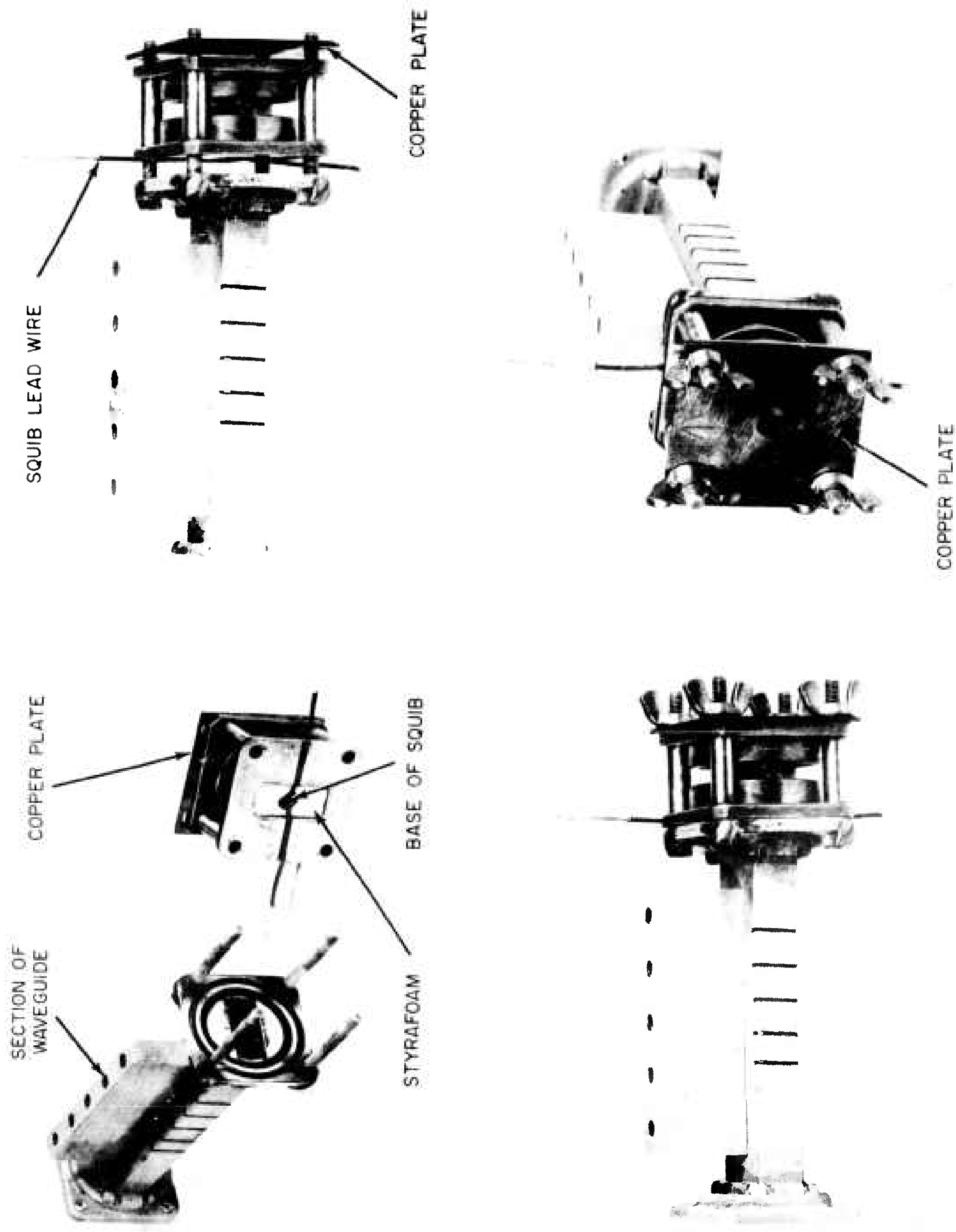


FIG. 6 DETAILS OF SQUIB HOLDER

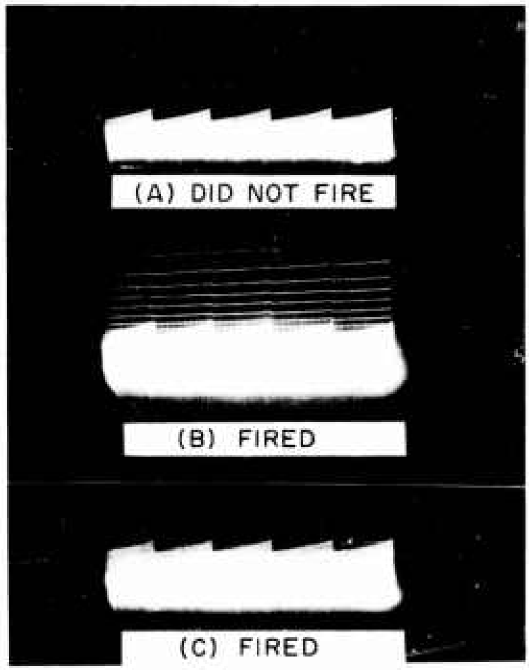
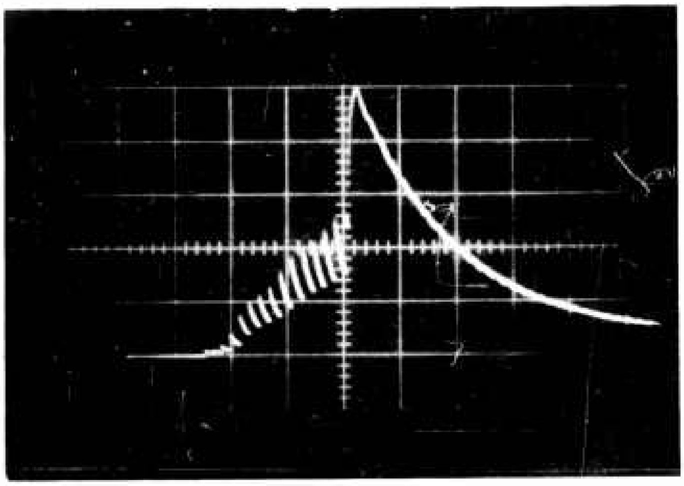


FIG. 7 TYPICAL OSCILLOGRAMS FOR CONTINUOUS INPUT



0.10 SEC

FIG. 8 TYPICAL OSCILLOGRAM FOR GATED FIRING, SQUIB FIRED

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SUBJECT ANALYSIS OF REPORT

DESCRIPTORS	CODES	DESCRIPTORS	CODES	DESCRIPTORS	CODES
Squib (tests)	SQUIT	Prediction	PRED	Hazards	HAZA
1 Mod 0	1MØN	High frequency	HIGF	Electromagnetic	ELEM
Sensitivity	SENV	Powder	POWD	Radiation	RADT
Radar	RADR	Charges	CHAR	Electroexplosive	ELEX
Pulses	PULS	Attenuators	ATTN	Devices	DEVI
Equipment	EQUI	Reduction	REDC		
Bridge	BRID	Probability	PRBA		
Wire	WIRE	Radiofrequency	RADF		
Temperature	TEMP	Fields	FIEL		
Firing	FIRI	Response	RESP		
Squib	SQUI	Hero	HERT		
Simulators	SIML	Project	PRJE		

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Naval Ordnance Laboratory, White Oak, Md.
(NOL technical report 62-77)
CHARACTERIZATION OF SQUIB MK 1 MOD 0; SENSITIVITY TO 9KMC RADAR PULSES, by I. Kabik and C. Goode. 31 Aug. 1962. 25p. illus., tables, diagr. Task NOL 443. UNCLASSIFIED

Mk 1 Mod 0 squibs were fired in wave guide of 9KMC radar. For fully loaded squibs, on basis of previous tests at D.C. to 5 megacycles, bridgewire in 9KMC tests did not reach temperature expected necessary for firing. Squibs without cup or base charge approximated expected firing temperature. Squib simulators used to predict firing on basis of bridgewire temperature may not be applicable at frequencies as high as 9KMC. Powder charges in some devices may act as attenuators somewhat reducing probability of firing in high frequency RF fields.

1. Squibs - Mark 1 mod 0
2. Squibs - Firing
3. Squibs - Sensitivity
4. Electroexplosive devices - Sensitivity

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III. Goode, Charles W. jt. author
IV. Project

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